In situ Validation of the Source of Thin Layers Detected by NOAA Airborne Fish Lidar

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LONG-TERM GOALS

Our long-term goal is to understand how physical-biological, biological-biological and chemical-biological interactions control the formation, maintenance and dissipation of thin layers of plankton and how the resulting thin layers impact *in situ* and remote sensing technologies of critical interest to the Navy. We are also interested in improving our ability not only to detect, characterize and map the temporal and spatial extent of thin layers, but also to improve our ability to predict their occurrence in a variety of ocean environments.

OBJECTIVES

Our short-term objective is to evaluate the relative importance of large non-spheroid phytoplankton and zooplankton in generating the thin optical backscattering layers detected by the NOAA airborne fish lidar in a variety of coastal and oceanic environments. The existing system clearly has the capability of detecting thin layers and mapping their coherence and spatial extent in a wide variety of coastal and oceanic environments.

APPROACH

The approach was to use a series of field experiments to evaluate the source of the thin layers of high backscattering detected by airborne fish lidar. We are particularly interested in determining the degree to which the cross polarization detector system (and other characteristics) of the airborne fish lidar make it sensitive to thin layers of large, non-spheroid phytoplankton and/or zooplankton, or other types of layered particulate material that are common in coastal waters. In designing these field experiments, we have tried to minimize costs while maximizing the chances of *in situ* verification/validation of the sources of thin layers that can be detected by the NOAA fish lidar. Given this, we designed a series of field experiments where we deploy the fish lidar from a small plane and use real-time analysis of lidar data to identify areas with thin backscattering layers that Dr. Donaghay and coworkers from the University of Rhode Island would sample with a small boat equipped with the *in situ* optical sensors and discrete sampling systems needed to verify and optically characterize the source of the observed lidar signals. Real-time analysis of the lidar data was facilitated by transmitting the lidar data to the

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14. ABSTRACT
Our long-term goal is to understand how physical-biological, biological-biological and chemical-biological interactions control the formation, maintenance and dissipation of thin layers of plankton and how the resulting thin layers impact in situ and remote sensing technologies of critical interest to the Navy. We are also interested in improving our ability not only to detect, characterize and map the temporal and spatial extent of thin layers, but also to improve our ability to predict their occurrence in a variety of ocean environments.

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surface in real time so that all of the information that would be available to an airborne operator is available to the scientists on the boat.

The University of Rhode Island group mapped the vertical and horizontal extent of detected thin layers using a vertically undulating Sea Sciences Acrobat tow body equipped with a Sea Bird SBE 49 CTD to measure physical structure, a pair of WET Labs ac-9s to measure spectral optical absorption and attenuation by dissolved and particulate material, a WET Labs VSF to measure optical backscattering at 532 nm, and a Brooke Ocean Technologies Laser Optical Plankton Counter (LOPC) to measure the abundance, size, and shape of zooplankton. Aircraft and ship sampling were coordinated to maximize overlap of sampling both in areas where the airborne lidar detected layers and in nearby waters where it did not detect layers. Discrete samples were also collected from inside and outside layers (thick or thin) once the towed system identified the location of layers of phytoplankton and/or zooplankton that were also detected by the airborne lidar. The zooplankton samples were collected using a pump and the phytoplankton samples were collected using a siphon sampler and a small rosette bottle sampler. These samples will be videotaped live on stereo and compound microscopes, and preserved for further analysis in the lab.

The choice of a May campaign in the East Sound was made for several reasons. First, past work in this area gives Donaghay, Sullivan and Rines considerable confidence that we can not only expect the periodic occurrence of intense thin layers of phytoplankton and zooplankton, but that we can also sample these layers from small boats that can be used at low cost and operated in a highly flexible manner (we have past experience in leasing small vessels, using vessels provided by UW APL or Friday Harbor Labs, and in contracting with local fishermen). Second, Churnside has experience working with a retired NOAA pilot in the area who has a small aircraft suitable for flying the lidar system. Equally importantly, the pilot is flexible and interested in the proposed effort and willing to participate at a very reasonable cost. This combination of past experience in the area as well as low cost and flexibility of both airborne and ship operations should maximize our chances of success while minimizing costs, despite the high lidar attenuation typical of inland waters.

WORK COMPLETED

The first field experiment was successfully completed, with flights on 11 consecutive days. We have begun data analysis by looking at the temporal evolution of lidar profiles near the mooring and of the lidar attenuation coefficient near the surface along East Sound and into the channel at the mouth of the sound. We have also begun calculations of the scattering from pennate diatoms as a first step toward modeling the lidar return.

RESULTS

The lidar was able to detect thin scattering layers in East Sound (Fig. 1) and direct the boat to those layers. Identification of the scattering particles detected by the lidar was accomplished much more accurately than expected, since the scattering layers were composed of a single species.

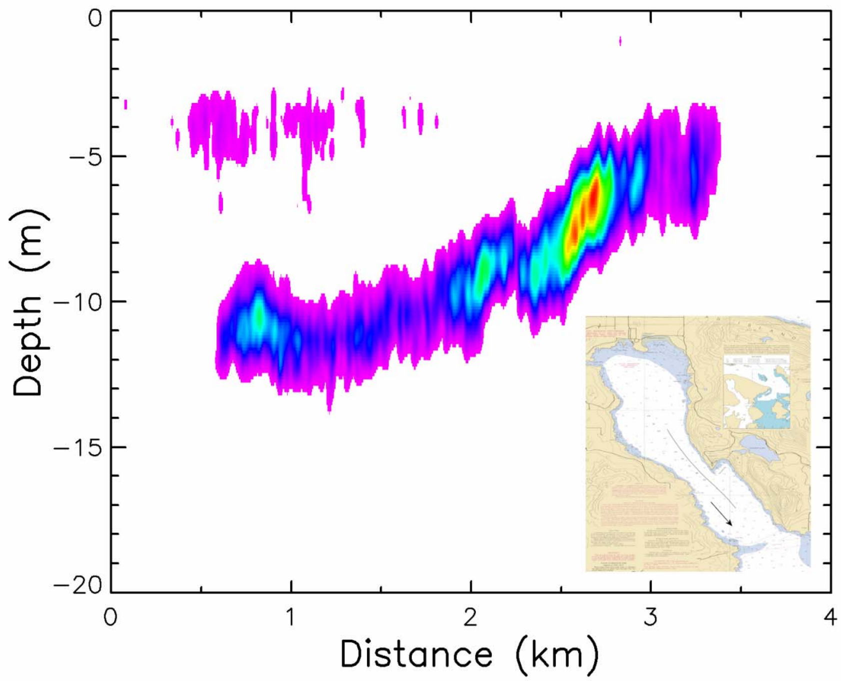

Fig. 1. Lidar echogram of a scattering layer in East Sound showing relative scattering intensity as a function of depth on the vertical axis and distance along the flight track on the horizontal axis. The figure shows a layer that starts at a depth of 11 m at 600 m into the flight track segment and ends at a depth of 5 m at 3300 m into the flight track, with the most intense portion near 2700 m. The embedded chart shows the flight track segment and the direction of travel.

From the lidar data analyzed to date, we have developed the following picture of the evolution of the plankton bloom during the observation period: At the beginning of the period, there was a dense bloom from the surface down to about 5 m depth in the sound. This did not extend out into the channel, where the water was clearer. After about three days, the surface water in the sound began to clear, and the bloom settled into a layer at about 8 m. Over two days, the depth increased to about 12 m, and the surface water continued to clear. By the end of the measurements, the layer had dissipated, leaving relatively clear water from the surface to the lidar penetration depth of about 20 m. By this time, the water in the channel outside the sound had become more turbid (Fig. 2). The likely cause is the increasing influence of Frazier River water due to increasing tidal effects. The next step in data analysis will be to compare these features from the lidar data with the detailed in situ measurements taken by the University of Rhode Island group. The single-species bloom evolving over time that we observed is ideal for this type of comparison, because of its relative simplicity.

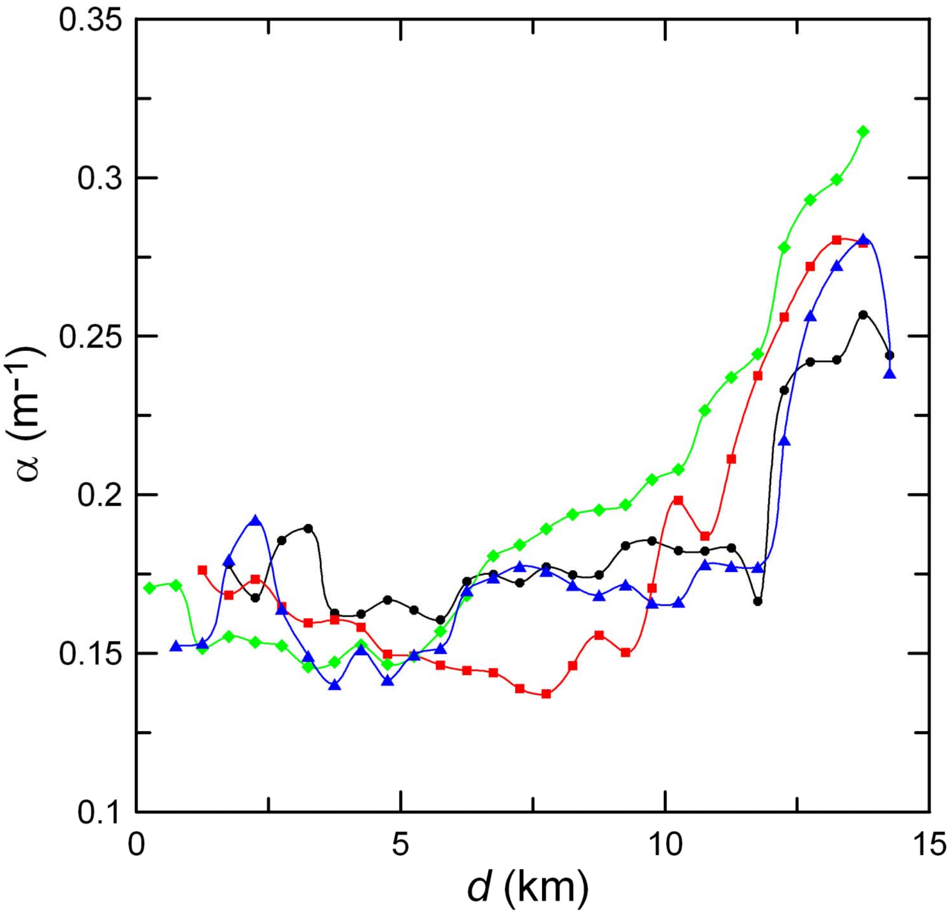

Fig. 2. Lidar attenuation α as a function of distance from the head of the sound d for 23 (black), 24 (red), 25 (green), and 26 (blue) May 2009. Values are between 0.15 and 0.17 m^{-1} within the sound, which extends to about 10 km, and increase to greater than 0.25 m^{-1} in the channel beyond 10 km.

IMPACT/APPLICATIONS

Our re-analysis of 80,000 km of data collected by the NOAA airborne fish lidar developed by Dr. Churnside has shown that this system has the capability to rapidly detect and synoptically sample the spatial extent, intensity and prevalence of thin (and not so thin) backscattering layers in a wide variety of coastal and oceanic waters (Churnside and Donaghay, 2009). The specialized optics, extremely high data rates (10^9 samples/sec), 5 to 10 m horizontal resolution and better than 50 cm vertical resolution of the fish lidar provide an unparalleled synoptic picture of optical fine structure of the upper 50 m of the ocean. Our search for thin layers in this data has not only greatly increased our understanding of the spatial extent and the types of environments where thin layers can occur, but it has also given us new insights into the role of large scale forcing in controlling their occurrence. For example, not only has it shown that thin layers can be equally prevalent in shallow and deep ocean environments during upwelling relaxation events, but also that thin layers can extend uninterrupted for more than 10 km in regions with strong internal wave activity. However, since *in situ* verification/validation efforts have thus far been driven by the need to rapidly assess fish stocks (NOAA's objective in developing the lidar), we can only speculate about the source of the thin layers that are so evident in the data. As a

result, we can only hypothesize that the thin layers in the lidar data are the result of backscattering by thin layers of highly non-spheroid phytoplankton and/or zooplankton that frequently dominate the thin layers we and our colleagues in LOCO have detected using *in situ* bio-optical and acoustical profilers. Given the potential impact of thin optical backscattering layers on underwater imaging sensors, diver visibility and remote sensing system technologies, we feel it is critical to increase our understanding of the source of the signal. This work is the next logical step in our efforts to be able to predict and/or remotely detect the occurrence and impacts of thin plankton layers while at the same time leading to the development of a set of tools that the Navy can use to meet their research and operational needs. We are particularly excited about the potential breakthroughs that will occur when we can combine (a) recent advances in bio-physical modeling, (b) the capabilities of airborne lidar to spatially map fine-scale structure, and (c) the capabilities of autonomous profilers to quantify temporal and spatial changes in fine-scale physical, chemical, bio-optical and bio-acoustical structure.

RELATED PROJECTS

This is a joint project with Drs. Donaghay, Sullivan, and Rines at the University of Rhode Island. The title of their portion is the same, but they are funded through a grant.

REFERENCES

Churnside, J. H. and P. L. Donaghay (2009) Thin scattering layers observed by airborne lidar," ICES J. Mar. Sci. **66,** 778-789.